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ROTOR FLOW RESEARCH IN LOW SPEED HELICOPTER FLIGHT

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For the Period
July 1, 1979 - April 30, 1981

U.S. ARMY RESEARCH OFFICE
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements of helicopter rotor wake flow were made at low advance ratio. Both steady and non-steady data were taken in the wake using 3-D hot-film anemometry. Emphasis was placed on the presentation of the data. Motion pictures were obtained from the computer plots of the experimental velocity data.

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Final Report

Project DAA-29-79-C-0074

Rotor Flow Research in Low Speed Helicopter Flight

September 1981

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Rotor Flow Research in Low Speed
Helicopter Flight

Statement of Problem: To measure and present the instantaneous velocities in the wake of a helicopter rotor operating at low advance ratios.

Introduction

Earlier work conducted in the study of rotor wakes at low advance rotors was concentrated upon obtaining a large amount of data on the time-averaged velocities in the wake of a helicopter rotor at very low advance ratio. These results have been previously reported.(1,2,3) In that work it was found that the overall wake rolled up very quickly with the roll-up seeming to occur through the rotor plane as though the rotor were a porous low aspect ratio wing. In addition, the rolled up vortex structure seemed to concentrate the fluid coming to the rotor into two concentrated streams which were being squeezed to the rear in concentrated tubes.

The present work which is now being reported deals with the non-steady nature of the wake and its presentation.

As discussed in the final report to a previous contract, DAA-G-29-76-G-0260, the non-steady instrumentation system to measure the velocities was developed into a potentially useful form. Since it was planned to explore a large region under the rotor, a massive data handling requirement existed. The systems which evolved used three mutually perpendicular hot-wires (hot films) mounted in a traverse system. Output voltage signals from the hot-film probes were sent through conditioning equipment to a PDP-11 computer and almost instantaneous information on

velocities sent back to the test operator at the test site. This interactive mode allowed the massive data acquisition system to be handled in a practical manner. Some details of the system may be found in Appendix A which is extracted from reference 4.

In an attempt to exploit the capability achieved with the data system in the study of the rotor wake, further modifications to the system were undertaken, and means of presenting non-steady data to the observer and research engineers in the field were started.

Description of the System

As has been reported previously a model helicopter rotor, two and one half feet in diameter is mounted in a low speed wind tunnel.(1,2,3) Advance ratios in the range of $\mu = 0.04 \rightarrow 0.10$ are run. In the data reported on herein the advance ratio of $\mu = 0.06$ was chosen as being representative. The velocity field below the rotor is surveyed by an x-y-z traverse mechanism which moves the velocity probe into a possible 1188 positions. The velocities at any point are determined by means of a three-dimensional hot-film probe. The voltage outputs from that probe are accepted by an on-line computer, digitized by an A-D converter, processed and displayed as velocities on a T.V. monitor at the test site.

System Considerations

Based upon the success achieved with the data handling system it was decided to try to improve the system representation of the non-steady velocities, to seek means of presenting the data in graphical form on the T.V. monitor, and to provide motion pictures of the observed variation in the velocity vectors.

During the study of the initial velocity data taken of the time varying wake, it was perceived that the traces of each component of velocity at a point did not repeat exactly. Typical traces are shown in Figure 1. This had been anticipated and an averaging method had been applied as indicated in Appendix A. Review of the data indicated that the traces, although similar in shape, seemed to shift slightly in time (i.e., azimuth position) so that the peaks and valleys did not match. To attempt to correct this, a system to shift the waves was developed and tried.(5) The results of many trials indicated that the simple averaging method shown in Appendix A gave the best results. Consequently that method was used throughout the work.

To present the data in an orderly manner, and to present it in a way that could be interpreted, computer programs were written or existing ones modified so that the output velocity vectors representing the wake could be presented on the T.V. screen. This was essentially completed very shortly after the initiation of the work under this phase in spring of 1980. Unfortunately, at about the time the presentation system was being checked out and debugged, a system failure in the PDP-11 inadvertently led to an essentially complete wipe out of the data presentation system. It was then necessary to re-write, program and debug the presentation system. Shortly after this problem occurred, troubles also developed with the hot-wire anemometry which ultimately required modification and reworking all three commercial hot wire anemometers. When both of these problems were corrected, it then became practical to re-enter the tunnel, take data interactively and then move on to the film animation of the output.

Results Achieved

With the revised hot wire and computer graphical output systems working, tests were run to measure the velocity field at air advance ratio of $\mu = 0.06$, a tip speed of 300 feet/sec, a collective pitch of 8° at the 75% radius, a blade twist of 8°, and a shaft tilt forward of 8°. Since data are taken and averaged for every 5° position of the rotor, for any plane parallel to or transverse to the rotor, there are 72 "pictures" of the velocity vectors in that plane. Thus it was believed that these planes could be photographed in succession and the changes of the velocities in any plane could be viewed as they changed as the rotor rotated. Figures 2-4, illustrate the vectors at the azimuth position of 355° for the reference blade. It may be noted that these are similar in nature to the time averaged data shown and reported previously.(2,3,4) It would be possible to present similar data for all other 71 positions around the azimuth since the data are developed and stored on a floppy disk. It, however, is simply not practical to make and report 1600 pages of vector plots. At best no one would examine them. Instead, photographs of each plane of data were made directly from the cathode ray tube screen, and subsequently displayed as a motion picture.

Viewing the motion picture of each plane reveals some local changes to the nature of the flow. Rather surprisingly, large changes due to concentrated vortex passages do not occur with any regularity. Occasionally some vector changes which might depict vortex are seen but in general the evidence is more of small, gradual changes.

The two motion picture films produced under this contract are considered to be the primary output of the effort expended on this contract. The films should be viewed only after review is made of the

format of vector plots shown in the references 1, 3, 4 and 5. This is necessary in order that the viewer can recognize readily the planes used and the directions indicated.

Publications

Masters Theses:

Terkel, Hanan, "Non-Steady Velocity Measurements of the Wake of a Helicopter Rotor at Low Advance Ratios", 1980
Navarro, Richard, "Development of a Computer Based Presentation of Non-Steady Helicopter Rotor Flows", 1981

Paper:

Submitted to the American Helicopter Society for the National Forum, 1981

"Measurements of the Non-Steady Velocities in the Wake of a Model Rotor at Low Advance Ratios"

Submitted to the International Journal, Vertica 1981, "Velocities in the Rotor Wake at Low Advance Ratios as Determined by Hot Wires"

List of Participating Scientific Personnel

Henry R. Velkoff, Principal Investigator

Hanan Terkel, Graduate Student
Fu Kuo Shiao, Graduate Student
Richard Navarro, Graduate Student

All three graduate students earned the Master of Science degree while working on this project. Mr. Terkel and Mr. Shiao did most of their studies under the previous contract but completed their work under this project.

References

1. Velkoff, H. R. and Horak, D., "Rotor Wake Measurements at Very Low Advance Ratios", Am. Hel. Society Proceedings, Washington, D.C., May 1979.

2. Horak D. and Velkoff, H. R., "Direct Frequency Response of Hot-Wire and Hot Film Anemometers", Winter Annual Meeting of the ASME, San Francisco, December 1978.

3. Velkoff, H. R., Terkel, H., and Shaio, F. K., "Effect of Changing Rotor Parameters on Rotor Wake Velocities at Low Advance Ratios", Fifth European Rotorcraft and Powered Lift Symposium, Amsterdam, Netherlands, September 1979.

4. Terkel, H., "Non-Steady Velocity Measurement of the Wake of a Helicopter Rotor at Low Advance Ratios", M.S. Thesis, The Ohio State University Mechanical Engineering Department, Columbus, Ohio, March 1980.

5. Navarro, R. R., "Development of a Computer Based Presentation of Non-Steady Helicopter Rotor Flows", Department of Mechanical Engineering M.S. Thesis, The Ohio State University, Columbus, Ohio, August 1981.

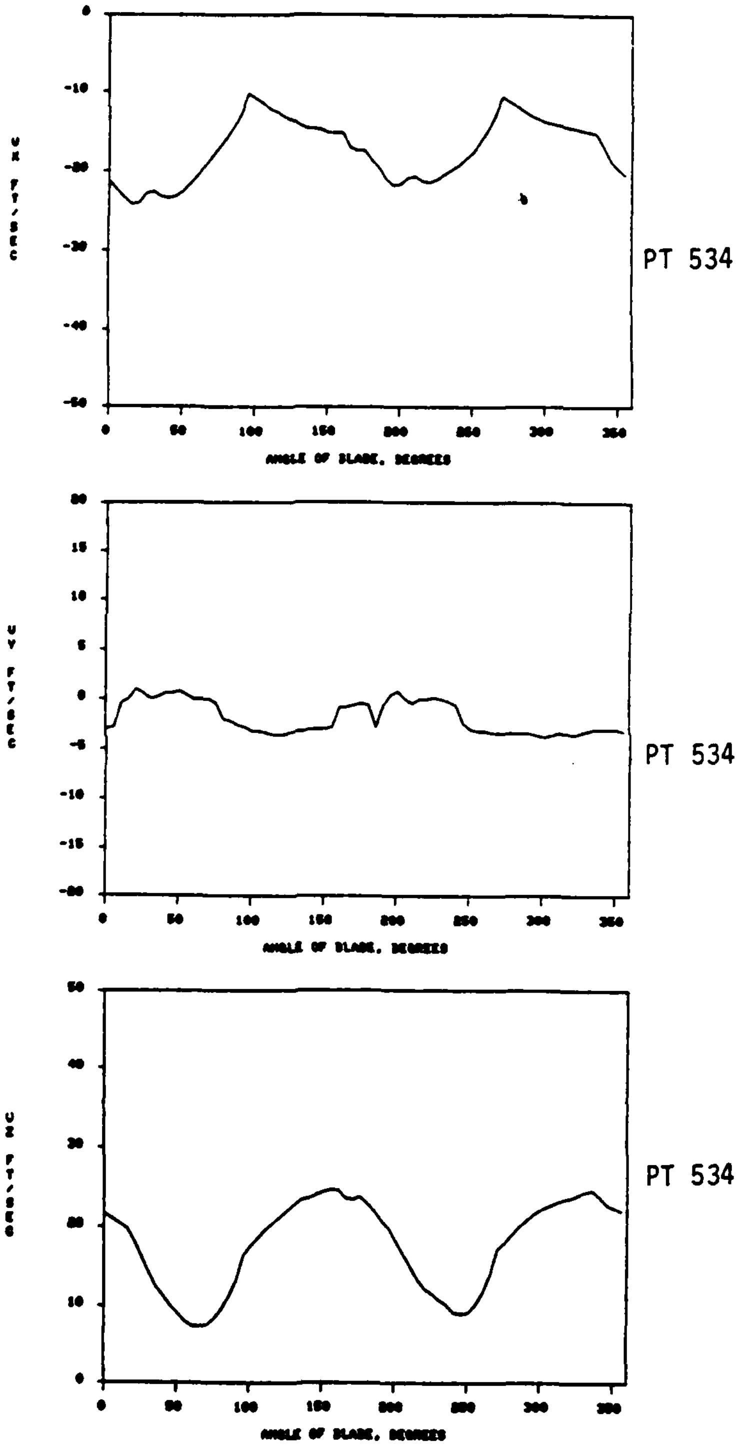

Figure 1. Azimuth Varying Velocities for 1 Blade Revolution at a Probe Position Y/R = 0.27 and X/R = -1.07. Where R = rotor radius, Y is lateral distance from center, and X is distance aft from center.

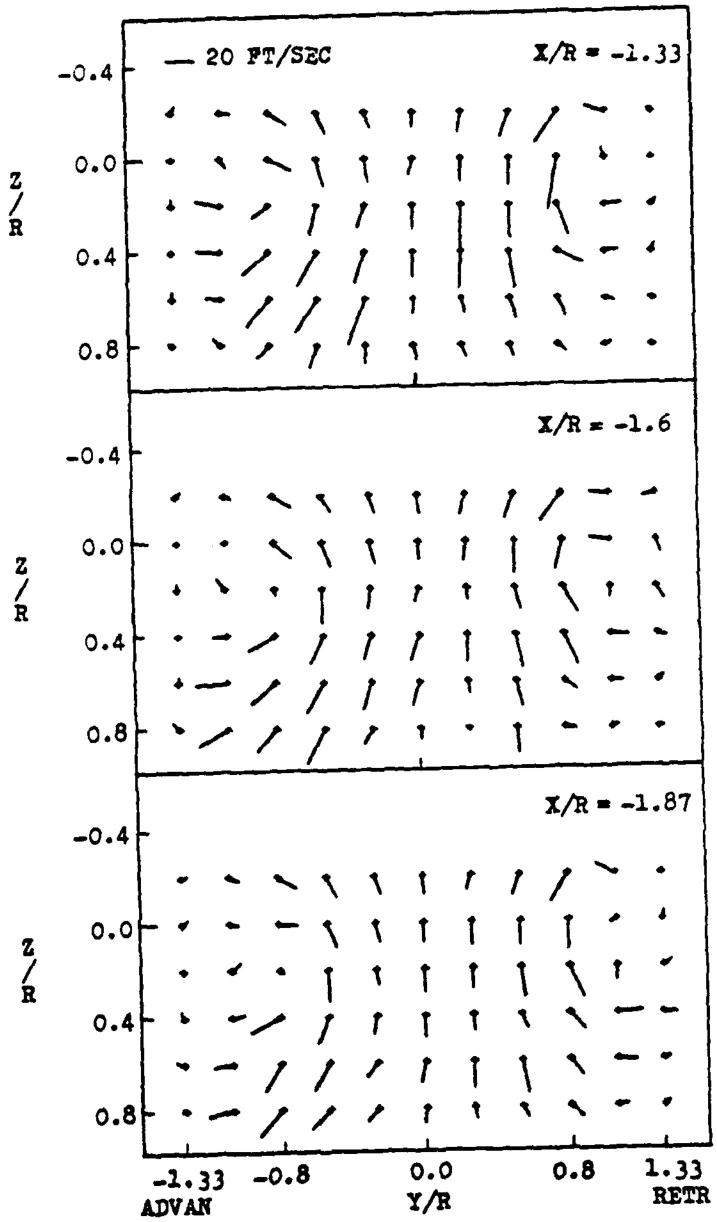

Figure 2. Typical Velocity Vectors in Planes Perpendicular to the Tunnel Flow. Planes Located Downstream from the Rotor. Azimuth Angle is 355°. X/R is Distance from Rotor Center Along Tunnel. Y/R is Distance Laterally from Center. Z/R is Distance Below Rotor.

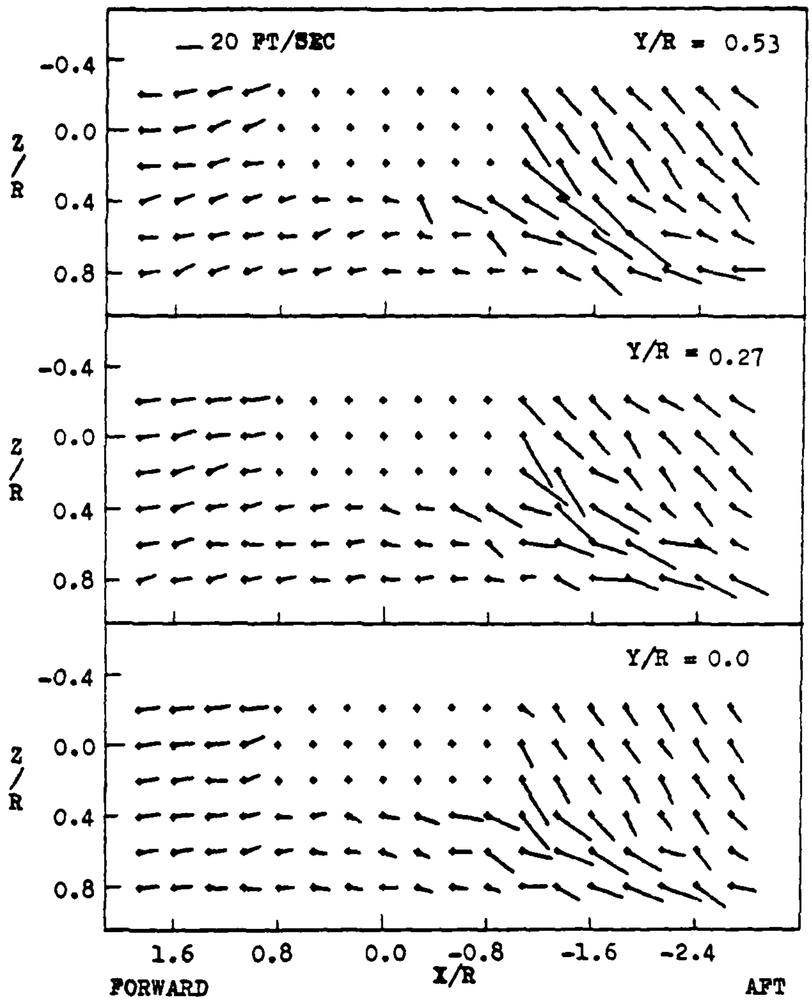

Figure 3. Typical Velocity Vectors in Planes Perpendicular to Rotor Plane and Parallel to Shaft Axis. Azimuth Angle is 355°.

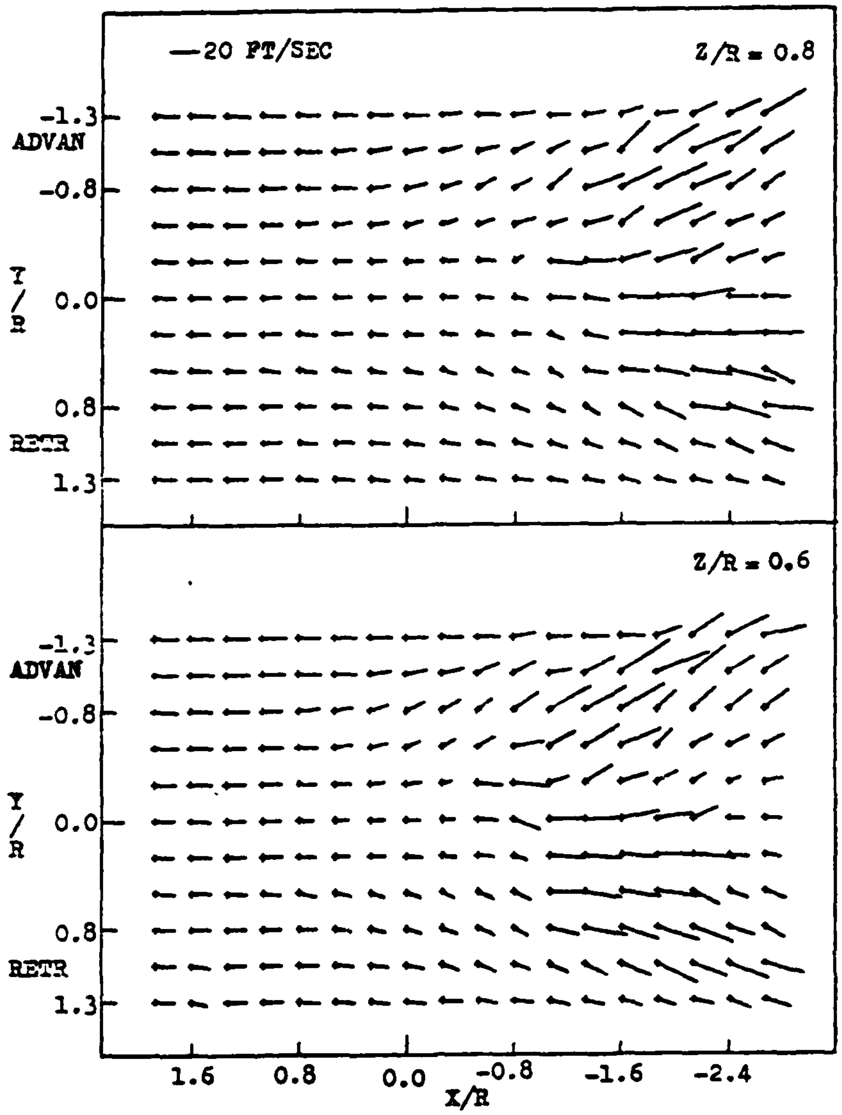

Figure 4. Typical Velocity Vectors in Planes Parallel to the Plane of the Rotor. Azimuth Angle is 355°.

APPENDIX

An Interactive Method of Measuring Average Instantaneous Velocities of a Rotor in Very Low Advance Ratios

The new minicomputer installed in the department of Mechanical Engineering at The Ohio State University provided the means of improving the system of average data acquisition and extending the work to average instantaneous velocities measurement.

The minicomputer is a DEC PDP 11/60 and is well suited to the Fortran based calculations. It has a 250 KBYTES memory (RAM) and 64 KBYTES are available to the user. The PDP hosts graphics (Tektronix 4014-1) and alphanumeric (Infoton) terminals. The terminals are supported by a high speed Printronix Printer-plotter and a Tektronix hardcopy unit. Data and program storage are provided by a dual floppy disc drive and two RKO cartrige dics drives.

Two A/D converters are available for data acquisition: 1) DEC LPA system which can sample up to 40 KHz and can be multiplexed up to 16 channels, with a multichannel interval of 22 μ sec.; 2) GENRAD 4 channel A/D System (ADS) with a sampling frequence of 160 KHz and a multichannel interval of 6 μ sec.

For the present application the four channel GENRAD ADS will be used initially because of its higher sampling frequency and lower multichannel time interval. However, if

more channels may be needed (for a fully automated process, where the computer controls the RPM of the rotor and the X-Y-Z location of the probe) the DEC LPA system can be used and the 22 μ sec. error, between any sequent channels, can be compensated for by means of delay lines.

Data Acquisition System

The data acquisition system will consist of the following components (Figure 1): 1) Computer; 2) A/D converter; 3) Alphanumeric terminal; 4) Interface; 5) Velocity measurement system (hot-film anemometer). A 500 ft. cable (eight twisted pairs individually shielded) was extended from the computer room on the second floor of the Mechanical Engineering building to the first floor where the windtunnel is located. The connection with the computer is complete. The dynamic effect of the wires on the analog signals and particularly on the triggering signal is yet to be investigated.

The development of the software was initiated. At this early stage of design, it seems that two programs, for average data and for average instantaneous data will be needed, because of limited storage space. However the outline for both programs is similar:

1. As long as the data acquisition is not fully automated the process should be interactive.
2. The bookkeeping should be done by the computer, and the operator will be instructed by the

computer how to proceed.

3. The data collection procedure would be that continuity from previous days will proceed with a minimal information input needed from the operator.

4. The operator would be able to repeat the last data point without disturbing the normal flow of operation, to provide a check.

5. If more then the last point has to be repeated this would have to be done by interrupting the normal procedure.

Average Data Collection

Mean value data averaged over several rotor revolutions can provide average velocity, and that about 1½ KHz contains the significant frequency content of the wake. For a correct reconstruction of the wave the sampling frequency must be at least 2000 Hz. An array, filled with the digitized values, having the dimension (2000,3) will be filled in one second, which corresponds to about 40 revolutions. At each location in the wake the data will be, averaged, the effective velocities calculated, and transformed to windtunnel coordinates. The three components of velocity (Vx, Vy, Vz) and the location of the probe (X-Y-Z) will be stored on the computer's hard discs. After the whole case will be finished the file will be transfered to the large ADMAHL 470 where the SPEAKASY language would be used for the vector plots.

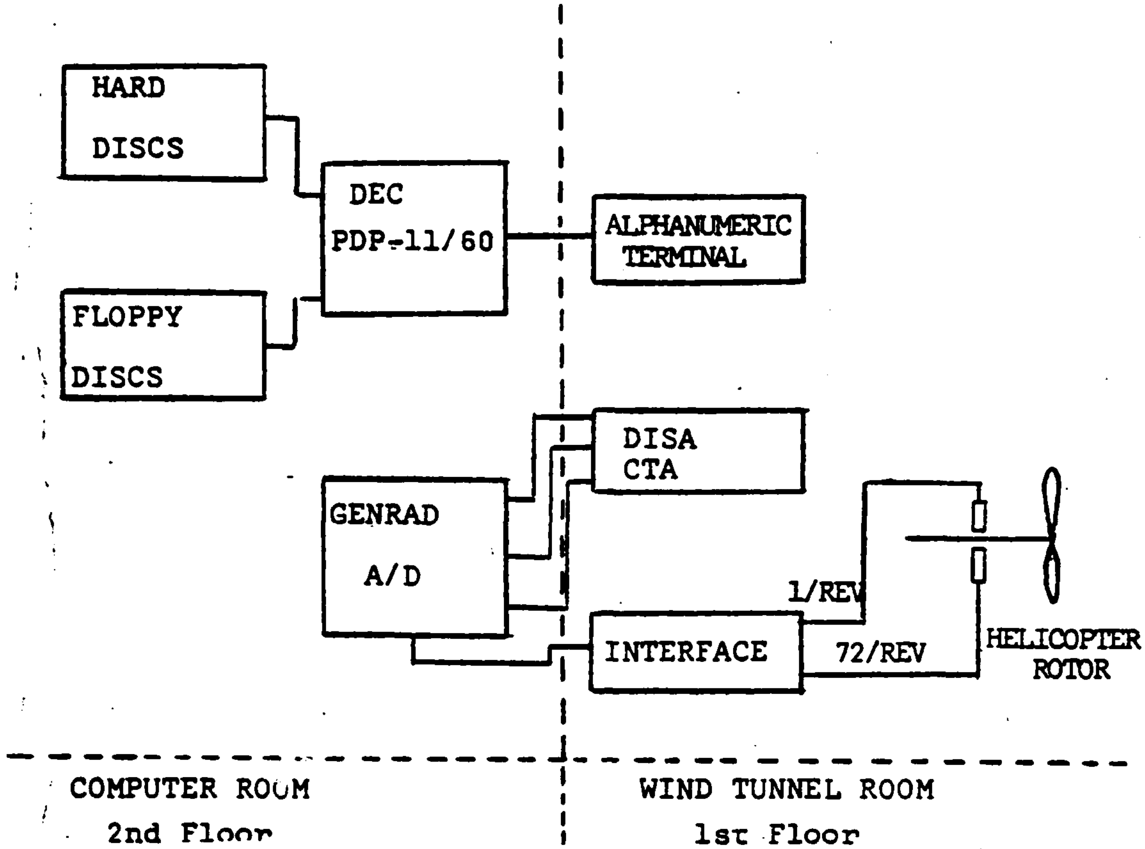

Figure 1. DATA ACQUISITION SYSTEM.

Instantenous Data Collection

For the average instantaneous data collection two methods will be developed: 1) Computer on-the-line with the ADS; 2) The whole case will be recorded on a FM analog recorder (PI-6100) and then reproduced at the ADS. An interface should be designed and built. It's basic specifications and requirements were provided to the electronic lab in the M.E. department, and it is expected to have it operational at the beginning of October 1979.

Computer Mode Operation

The inputs to the interface are:

1. 1/REV pulse from a magnetic proximity pickup indicating $\psi = 0$.

2. 72/REV pulses from a second magnetic proximity pickup indicating 5 degrees increments in rotor rotation. The output from the interface will be one pulse at each 5 degrees increment for 10 revolutions (Figure 2).

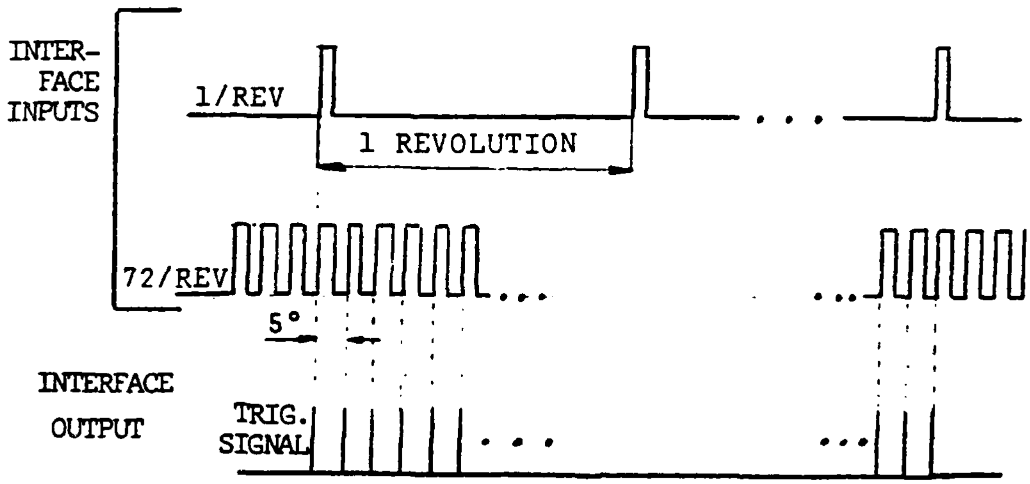

Figure 2.

The ADS will be initiated by the software, but the digitizing process will start when the operator will signal, from the interface, that the probe is at the correct location. Then, the ADS will be triggered every 5 degrees by the

triggering output from the interface. After the digitizing process has been completed, the computer will average the data for every 5 degrees increment for 10 revolutions. The three averaged voltages will be transformed then in the usual manner in wind tunnel coordinates. These velocities and the probe location will be stored, temporarily, on the computer's hard discs until the case is completed. Then the data will be stored, permanently, on floppy discs for further use and reference.

Tape Mode Operation

At this mode of operation, the interface has a dual purpose. When recording the data, it will produce the triggering signals for each 5 degrees increment and will also operate the FM tape recorder. The procedure is as follows: The operator will signal, from the interface, that the probe is at the correct location, then the device will start the tape recorder and after 0.5 second delay (to let the tape get to its steady state velocity) the analog data will be recorded on 3 channels. On the fourth channel the triggering signals will be recorded. After 10 cycles have been counted the interface will stop the recording. In the reproduction process the three analog channels will be connected directly to the ADS and the fourth channel with the triggering signals will be connected to the interface whose role now will be the same as in the computer mode.

Data Presentation

The numerical values of the velocities and their location will be stored on floppy discs and could be displayed on any terminal or printed out by the PRINTRONIX high speed printer. However, the vast amount of "numbers" (1188 points x (72 x 3 numbers per point) = 256608 "numbers") makes the use of data visualization a necessity.

For data visualization the TEKTRONIX 4014-1 graphics terminal will be used. This terminal has a refresh mode of operation and animated pictures of the wake as the rotor passes by, can be created. In addition, graphs of velocity vs. rotor position, or velocity vs. probe location can be obtained by using the PLOT-10 plotting routines available in the PDP's library.